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THE IMPACT OF HERBICIDE MODE OF ACTION ON LOW-DRIFT SPRAY EFFECTIVENESS

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The Impact of Herbicide Mode of Action on Low-Drift Spray Effectiveness

Final Report

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Abstract

Results from a three year project to study the interactive effect of spray quality, air amendment, and node of action on herbicide effectiveness are reported. Field studies evaluated 10 different herbicide treatments involving 16 different active ingredients and eight modes of action. Each herbicide treatment was applied at two rates (full label rate and either 0.75 x or 0.5 x, depending on the product), or in the case of Reglone, two rates and two carrier volumes. Six nozzle treatments were categorized by spray quality (medium, coarse, or very coarse) and air induction (yes or no). Herbicide performance was evaluated with visual ratings, weed biomass measurements, weed seed production, and crop seed yield. Results compiled over all three years indicated that mode of action and weed type significantly affected the type of response observed from the variables in the study. Group 1 and 22 products were most sensitive to application variables, with significant responses in 50% (only grassy weeds tested) and 33% (only broadleaf plants tested) of cases, respectively. A Group 4 and 6 tank mix and Group 8 were least sensitive, with 11% (only broadleaf weeds tested) and 17% (only grassy weeds tested) significant responses, respectively. Grassy weeds were much more sensitive to application variables (41% significant responses) than broadleaf weeds (24%). Within the broad-spectrum Group 10 and Group 2 herbicides , significant responses were more frequent for the herbicides' grassy (44% and 33%) compared to broadleaf (8% and 27%) targets for the two modes of action, respectively. Herbicide rate was the most important variable governing weed control, with an average of 58% significant responses (65% for grasses, 55% for broadleaves). In these cases, higher rates resulted in better control. Of the modes of action, Groups 1, 4, 9, and 22 were most sensitive to rates, and Groups 6 and 10 being least sensitive. Spray Quality had a significant effect on weed control an average of 17% of the time, 35% for grassy weeds and 10% for broadleaf weeds, with Groups 1 and 2 being most sensitive overall. In the majority of cases, there were no differences between medium and coarse sprays; instead, differences occurred between medium or coarse and very coarse sprays. Group 10, while only being sensitive to spray quality in 18% of tested cases, responded in 67% of grassy weed cases, but in no broadleaf cases. Air induction significantly affected weed control in 7% of tested cases, 10% for grassy and 6% for broadleaf weeds. Spray quality measurements indicated that sprays tended to deliver smaller droplets in the central region of the pattern, and coarser droplets near the edge. In particular, droplet numbers dropped significantly at the edges of the spray patterns. It is suggested that greater than 30% overlap may be required to maintain a uniform distribution of droplet size and number under the spray boom. Spray

retention of three spray qualities was similar for broadleaf species (tame buckwheat and tame mustard). For easy-to-wet broadleaf targets, spray retention was increased slightly with coarser sprays and air induction nozzles. Air induction also produced more uniform spray patterns, with retention values that were more similar under the nozzle centre and overlap compared to conventional sprays. For conventional nozzles on difficult-to-wet surfaces, the medium spray produced greater retention values than coarse and very coarse sprays. However, for air-induced sprays, coarse sprays were just as effectively retained on difficult-to-wet surfaces as medium sprays. Spray retention was reduced for very coarse sprays.

Executive Summary

- Field and laboratory experiments were conducted to study the interactive effects of spray quality, air induction, herbicide mode of action, and herbicide rate on weed control in wheat and canola, and desiccation of lentils.
- Field experiments were conducted at the U of S Kernen Research Farm near Saskatoon, and laboratory experiments were conducted at Agriculture and Agri-Food Canada's Saskatoon Research Centre.
- The experiments studied six nozzles: three nozzles were air induced, whereas three were not air induced. These nozzles delivered approximately medium, coarse, and very coarse sprays in each air-amendment category.
- Herbicide products were Horizon and DyVel tank mix, Freedom Gold (Assure and Refine tank mix), Everest and Buctril M tank mix, Avenge and Pardner tank mix, Roundup pre-seed, Rustler chem-fallow, Sundance, Accord, Liberty, and Reglone Pro
- Overall results indicated that weed control was rarely affected by application method. When effects occurred, they were limited to the very coarse sprays and grassy weeds. Herbicide rate was the more important factor determining herbicide performance
- In summary, low drift nozzles with or without air amendment were able to obtain commercially acceptable weed control in all cases for broadleaf weeds, independent of mode of action. Control was reduced for grassy weeds, with Group 1 being more sensitive than Group 2 products.
- Weed control was more frequently affected by herbicide rate than application method. Grassy weeds were more sensitive to these variables than broadleaf weeds.

- Spray droplet size varied with distance along the x-axis of the nozzle. Low-drift sprays contained fewer droplets overall, and edges of spray patterns contained coarser and fewer droplets than central regions. This observation has implications for overlap of sprays, as a traditional recommendation of 30% overlap will cause regions of suboptimal droplet numbers in the overlap region of the spray. Use of 50% overlap may provide a more uniform distribution of droplet size and density along the boom width.
- Spray retention amounts and uniformity were affected by weed type, spray quality, and air induction. Broadleaf weeds were much more efficient at retaining spray, capturing about six to seven times more spray on average than grassy weeds per g dry matter basis. Air induction improved retention uniformity along the width of the boom for broadleaf weeds and it allowed coarser sprays to be used on grassy weeds without loss of retention quantity.
- Results from this research have been extended in extension talks, conference proceedings, and in the form of fact sheets throughout Saskatchewan and Western Canada.

Technical Report

Background and Project Objectives

Management of spray drift continues to dominate in discussions of how to reduce the environmental impact of pesticides. Factors leading to decreased tolerance to drift include greater use of non-selective herbicides during times of acute sensitivity of the ecosystem (i.e. in herbicide tolerant crops), products with greater activity, and more diversification to sensitive special crops. Recent initiatives by the Pest Management Regulatory Agency (PMRA) to protect environmentally sensitive areas (such as shelter belts and water bodies) from drift damage through "buffer zones" can significantly restrict pesticide use on farm land.

New "venturi" nozzle technologies that dramatically reduce spray drift were introduced into Canada in 1997. These nozzles incorporate air into the spray pattern, and reduce drift by up to 95%. Since their introduction, more than ten different venturi-type nozzle models have become available and these are very popular with applicators. In 2000, a new line of pre-orifice low-drift nozzles (unlike venturi nozzles, pre-orifice nozzles do not use air-amendment) were introduced. It is not known how the lack of air-induction will affect biological performance of low-drift herbicide sprays.

The limiting factor to low-drift nozzle adoption is lack of knowledge in efficacy performance. Applicators are reluctant to use application methods that may reduce pest control, for which

they assume all risk. Conversely, agrichemical companies are reluctant to endorse low-drift measures if product performance may be compromised. The only way out of this dilemma is to provide good information to all parties. Lowering the risk, coupled with demonstration and communication of effective weed control with low-drift sprays, will enhance adoption of new methods, ultimately protecting the environment. Additionally, buffer zones may be reduced for low-drift application methods, providing encouragement for applicators to spray in a safe manner.

Research on the performance of pesticides often suggests the need for good coverage and a uniform pattern (Hislop, 1987). These requirements are traditionally achieved through the application of small droplets (Tuck *et al.*, 1997). In a comprehensive review of the effect of droplet size on herbicide efficacy, Knoche (1994) found that performance of 80% of herbicides influenced by droplet size. In 60% of studies, herbicide performance was improved with smaller droplets, whereas in 20% of studies performance improved with larger droplets. In the remaining 20% of studies, no effect was noted. Knoche also stated that the influence of droplet size on efficacy varied with pesticide and formulation, target species, carrier volume, and weather conditions. In general, as coverage of a plant increased, so did herbicide performance.

More recent research suggests that the relationship between coverage and performance may be more complicated. For example, Feng *et al.* (2003) suggested that although coarse droplets were not retained as efficiently as fine droplets, the coarse droplets provided the most efficient glyphosate uptake which more than compensated for the loss of retention. Wolf (2000) found that loss of efficacy with coarser sprays was more prevalent with grassy herbicides and weeds, and this loss could be mitigated by proper choice of spray pressure and application timing, or in another study, with improved deposit uniformity (Wolf et al., 1997). Nordbo *et al.* (1995) found that vertical targets received lower spray doses than horizontal targets, suggesting that improvements in deposition on such targets should be sought.

Recent years have seen the introduction of new spray technology, herbicide modes of action and formulations which had not been part of previous studies or reviews. It is therefore necessary to study how these new technologies impact herbicide performance so that applicators can make knowledge based decisions how best to apply sprays for drift control.

Objectives:

1. Establish the effect of conventional and air-amended drift reducing sprays on herbicide effectiveness.
2. Identify the limits of spray coarseness for various weed - herbicide combinations.
3. Study relationships between weed species and application method on spray deposition.

FIELD STUDIES

Crops were seeded at the U of S Kernen Research Farm in May of 2000, 2001, and 2002. Weeds were seeded into the plots as needed. Herbicides were applied when weeds and crops were at the recommended stage for treatment.

Treatments:

Nozzles: Three spray qualities using conventional flat fan and air-included tips were used (Figure 1). The objectives of these nozzle choices were (a) to determine the effect of commercially achievable spray quality, and (b) to determine whether air-inclusion played a role in a spray quality's efficacy performance. For practical reasons, the spray qualities could not be made to match exactly, but were deemed close enough to validate a comparison.

1. Non-air induced standard and pre-orifice flat fans at 40 psi
   - Wilger ER8002 (medium spray)
   - Delavan RF8002 (coarse spray)
   - Wilger DR8002/04 (very coarse spray)
2. Air-induced venturi tips, each at 70 psi, delivering the equivalent to an 8002 at 40 psi
   - Air Bubble Jet 110015 (coarse spray)
   - TurboDrop 110015 (very coarse spray)
   - Delavan (SprayMaster) Raindrop Ultra 110015 (very coarse spray)

Figure 1: Nozzles used in retention study

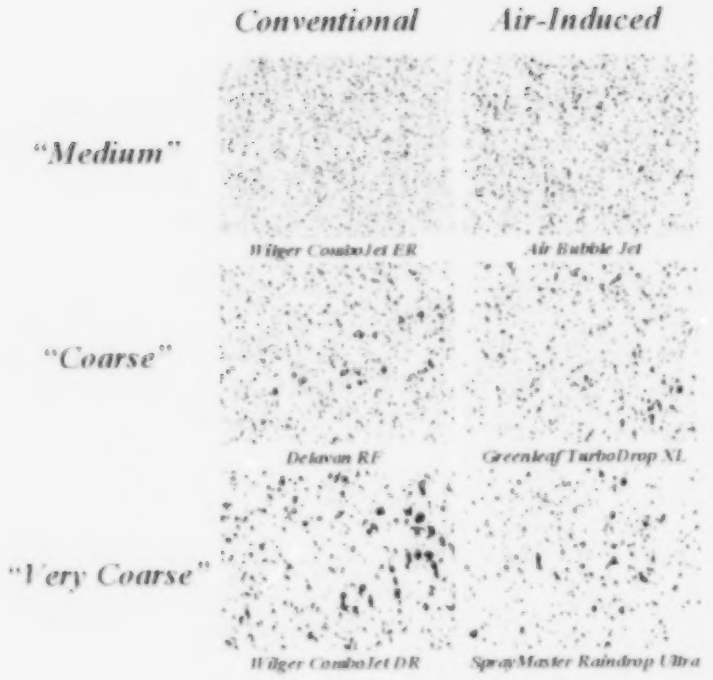

Figure 2: Spray deposits on water sensitive paper

Nozzles were calibrated by collecting output for 30 seconds from each nozzle. Pressures were adjusted as needed to ensure that all nozzles had equivalent output so that a single travel speed could be used. Pressures are shown in Table 1.

Spray nozzle fan angles were measured under laboratory conditions. With nozzles operated at the field spray pressure, spray fans were backlit and an adjustable long-arm protractor was held and adjusted to conform to the angle. All measurements were conducted twice.

Table 1: Nozzle pressures and fan angles.

Air Induction	Nozzle	Pressure	Fan Angle	
		(psi)	(°)	Visual
No	ER8002	32	81	
	RF8002	40	106	
	DR8002	35	80	
Yes	ABJ015	56	112	
	TD015	56	98	
	Ultra015	70	119	

Herbicides: Ten herbicide treatments, comprising 14 active ingredients and eight modes of action were applied (Table 2). Each herbicide was applied at two non-zero rates. An untreated control plot was included for each herbicide.

Table 2: Herbicide and crop treatments for the field experiments

Product	*Crop*	*Mode of Action Groups*	*Carrier Volume (L/ha)*	*Product Rates*
Horizon & DyVel tank mix	Wheat	1 and 4	100	**Horizon:** 0.238 L/ha and 0.119 L/ha **Dyvel:** 1.25 L/ha and 0.63 L/ha
Freedom Gold	"Clearfield" canola	1 and 2	100	**Freedom:** 20 g/ha and 10 g/ha **Assure II:** 0.5 L/ha and 0.25 L/ha
Everest & Buctril M tank mix	Wheat	2, 4, and 6	100	**Everest:** 43 g/ha and 32 g/ha) **Buctril M:** 1 L/ha and 0.75 L/ha

Table 2 (cont'd): Herbicide and crop treatments for the field experiments

Product	*Crop*	*Mode of Action Groups*	*Carrier Volume (L/ha)*	*Product Rates*
Avenge & Pardner tank mix	Wheat	6 and 8	100	**Avenge:** 4.25 L/ha and 3.19 L/ha **Pardner:** 1 L/ha and 0.75 L/ha
Roundup: pre-seed, Rustler: chem-fallow	Stubble	9 and 4	100	**Roundup (1st application):** 1.25 L/ha and 0.625 L/ha **Rustler (2nd & 3rd applic.):** 2.5 L/ha and 1.25 L/ha
Sundance	Wheat	2	100	28 g/ha and 21 g/ha
Accord	Canola	4	100	150 g/ha and 113 g/ha
Liberty	Canola	10	100	3.38 L/ha and 2.53 L/ha
Reglone Pro	Lentils	22	100 and 200	2 L/ha and 1 L/ha

Spray Application: All trials were conducted with a 4-nozzle 3-point hitch sprayer attached to a small tractor. Nozzle height was maintained at 50 cm above the targets for all treatments, although for the lentil desiccation, the height of the crop canopy prevented this maximum height from being achieved. Sprayer modifications are underway to correct this problem. Travel speeds were about 8.5 km/h.

Measurements: Weed control was visually assessed at two dates during the growing season. Weed biomass was determined by sampling two 1/4 m^2 quadrats in each plot. Weed counts were conducted as required. Grain yield and dockage was determined at harvest.

Experimental Setup: The field experiment comprised a total of 142 treatments (6 application methods * 2 rates + control *10 herbicides, plus 2 carrier volumes for Reglone). Each herbicide treatment was considered a separate experiment. Within each herbicide treatment, plots were laid out in a split plot design, with rates as main plots. Treatments were replicated 4 times.

Statistical Analysis: All data were subjected to analysis of variance (ANOVA). Parameters for any weed species were highly correlated, i.e., weed counts, biomass, and seed yield agreed with visual control ratings. As a result, visual control ratings at 36 days after treatment are reported here for simplicity. When a treatment effect was statistically significant according to ANOVA, box and whisker plots were generated to determine which treatments were different from others.

The frequency of statistical effects (herbicide rate, spray quality, and air-induction) were tabulated to identify trends with herbicides, weed species, and modes of action. For example, each combination of weed and herbicide comprised a 'case' from which a treatment effect (or lack thereof) could be determined. Data from all three years of study were compiled to determine frequencies of treatment effects. A total of 201 cases were thus available for analysis, 54 for grassy weeds, and 147 for broadleaf weeds or crops. These were divided by specific herbicide mode of action group, by contact or systemic mode of action, and by target plant type. Because Group 1 products appeared to be respond differently than the remaining systemic products, they were segregated for some analyses.

Results

Weather conditions were dryer than average for all three years of trials. Weed and crop emergence was variable and herbicide control was challenged by these conditions at times. In 2002, grasshoppers destroyed the plots shortly after spray application, resulting in the loss of data for several herbicides.

Table 3: Frequency of statistically significant herbicide rate, spray quality, and air-induction effects by mode of action group and weed type, 2000-2002.

Mode of Action Group	Grasses	n*	Broadleaves	n	G & B	n
1	50%	24	-	0	50%	24
2	33%	12	27%	33	29%	45
4	33%	3	29%	24	30%	27
9	-	0	37%	30	37%	30
6	-	0	11%	27	11%	27
8	17%	6	-	0	17%	6
10	44%	9	8%	24	18%	33
22		0	33%	9	33%	9
All	41%	54	24%	147	28%	201
Systemic	44%	39	31%	87	35%	126
Contact	33%	15	13%	60	17%	75
Systemic -1**	33%	15	31%	87	31%	102

* Number of observations
** Systemic products excluding Group 1 mode of action

Overall Effects: Specific results for each year of trials are tabulated in Tables 7 to 9. Figures of weed responses to application variables in 2000 and 2001 are shown in Figures 3 to 15.

Averaged over all the trials and years, treatment effects were observed in 28% of evaluated cases (Table 3). Grassy targets had a higher frequency of significant effects (44%) than broadleaf targets (24%). Surprisingly, systemic products had a higher rate of significant effects (35%) than contact products (17%). Although this result suggested that the systemic products were less tolerant of changes in application practice, the opposite may in fact be true. Consider that systemic herbicides often achieve higher and more consistent weed control than their contact counterparts. As a result, statistical significance is obtained with smaller actual differences than would be possible with a more variable and lower-performing contact product. For both systemic and contact products, effects on grassy plants were more frequent than those on broadleaf plants, but by a larger margin for contact (20%) than systemic products (13%). Group 1 products were largely responsible for the high frequency of significance on grassy plants within the systemic products, with 50% of effects significant. When these were removed from analysis, systemic products had a similar frequency in significant effects for grassy plants compared to contact products. Groups 1, 9, and 22 had the highest overall frequency of significant responses (50, 37, and 33%, respectively, and Groups 6, 8, and 10 had the lowest frequency (11, 17, and 18%, respectively).

Herbicide Rate: Of the effects tested, weed control responded most frequently to herbicide rate, with an average of 58% of cases responding (Table 4). In other words, herbicide rate reduction did not cause significant weed control loss in 42% of cases. Grasses responded more frequently to rate (65%) than broadleaves (55%).

Rate effects were more prevalent for systemic (70%) than contact products (36%), even after Group 1 products were eliminated from the analysis (57%). Among modes of action, Groups 22, 1, 4, and 9 were most sensitive to herbicide rate, with significant responses in 100, 88, 78, and 75% of evaluated cases. Groups 6 (22%) and 10 (27%) were least sensitive.

Table 4: Frequency of statistically significant herbicide rate effects by mode of action group and weed type, 2000-2002.

Mode of Action Group	Grasses	n*	Broadleaves	n	G & B	n
1	88%	8	-	0	88%	8
2	75%	4	45%	11	53%	15
4	100%	1	75%	8	78%	9
9	0%	2	90%	10	75%	12
6	-	0	22%	9	22%	9
8	50%	2	-	0	50%	2
10	33%	3	25%	8	27%	11
22	-	0	100%	3	100%	3
All	65%	20	55%	49	58%	69
Systemic	73%	15	69%	29	70%	44
Contact	40%	5	35%	20	36%	25
Systemic -1**	57%	7	69%	29	67%	36

* Number of observations
** Systemic products excluding Group 1 mode of action

Spray Quality: Weed control responded significantly to spray quality in 17% of cases, with 35% of cases occurring in grasses and 10 in broadleaves (Table 5). The frequency of significant spray quality effects was about one-third of that observed for herbicide rate. This could be interpreted to show that applicators are more likely to be successful at implementing changes in spray quality in their operation than changes in herbicide rate, although the low herbicide rates in this study were likely reduced more than those in commercial practice. Nonetheless, the relatively low frequency of responses was unexpected given the attention paid to spray quality by applicators, and the wide spray quality range evaluated in these studies.

Systemic products were more sensitive to spray quality than contact products (20% vs. 12%), particularly for broadleaves (14% vs. 5%, respectively). In both cases, grasses were several-fold more sensitive than broadleaves. Groups 1 (50%), 2 (27%), and 10 (18%) were most sensitive to spray quality, and Groups 6 (11%), 9 (8%), 22 (0%), and 4 (0%) were least sensitive. Systemic products without Group 1 became less sensitive to spray quality, at 14% compared to 33% with Group 1 included.

Table 5: Frequency of statistically significant spray quality effects by mode of action group and weed type, 2000-2002.

Mode of Action Group	Grasses	n*	Broadleaves	n	G & B	N
1	50%	8	-	0	50%	8
2	25%	4	27%	11	27%	15
4	0%	1	0%	8	0%	9
9	0%	2	10%	10	8%	12
6	-	0	11%	9	11%	9
8	0%	2	-	0	0%	2
10	67%	3	0%	8	18%	11
22	-	0	0%	3	0%	3
All	35%	20	10%	49	17%	69
Systemic	33%	15	14%	29	20%	44
Contact	40%	5	5%	20	12%	25
Systemic -1**	14%	7	14%	29	14%	36

* Number of observations
** Systemic products excluding Group 1 mode of action

The chosen method of analysis was intended to determine if spray quality had an effect, but it was not capable of identifying the best spray quality since this varied from situation to situation. However, the following observations appear justified: When spray quality had a significant effect, it was usually one of two situations. In the first, weed control was similar for medium and coarse sprays, and was reduced by about 10% for very coarse sprays. This was most common for grassy weeds. In the second case, most common for easy-to-wet broadleaf weeds, control was best with the coarse sprays and diminished slightly with both medium and very coarse sprays.

Air-Induction: Although the presence of air-induction proved to be the least important variable in herbicide effectiveness, the effect on weed control was mostly positive. Over the entire experiment, only 7% of air-induction effects were significant (Table 6). A slightly higher proportion of significant effects occurred for grasses (10% compared to broadleaf weeds (6%). Systemic products seemed to benefit more then contacts (9% vs. 4%). Groups 1, 4, 9, and 10 accounted for all the air-induction effects, with Group 1 benefiting more frequently than the others. Due to practical constraints in the experimental design, the air-induction effect was, in fact, a comparison between two brands of nozzles that likely differed in more than just air-induction. For example, the conventional nozzles were one size larger than the air-induced models (02 vs. 015), and were operated at lower pressures to equalize flow rates. These

differences may also be responsible for observed effects. Regardless, these results show that acceptable efficacy is just as likely with both nozzle types, particularly when opportunities for pressure optimization can be realized with the conventional nozzles.

Table 6: Frequency of statistically significant air-induction effects by mode of action group and weed type, 2000-2002.

Mode of Action Group	Grasses	n*	Broadleaves	n	G & B	N
1	13%	8	-	0	13%	8
2	0%	4	9%	11	7%	15
4	0%	1	13%	8	11%	9
9	0%	2	10%	10	8%	12
6	-	0	0%	9	0%	9
8	0%	2	-	0	0%	2
10	33%	3	0%	8	9%	11
22		0	0%	3	0%	3
All	10%	20	6%	49	7%	69
Systemic	7%	15	10%	29	9%	44
Contact	20%	5	0%	20	4%	25
Systemic -1**	0%	7	10%	29	8%	36

* Number of observations
** Systemic products excluding Group 1 mode of action

Conclusions

These field studies represent a comprehensive look at the application factors governing a wide range of common herbicide modes of action. Results can be summarized as follows:

- Herbicide rate caused changes in weed control in 58% of evaluated cases and the selection of the appropriate rate is therefore the most important application decision an operator can make.
- Spray quality affected weed control 17% of the time on average, but three times more frequently for grasses than broadleaves. Spray quality was therefore of significant importance for grassy herbicides (affecting efficacy 35% of time), but was only important for broadleaves 10% of the time.
- Air induction did not have a large effect on herbicide performance, although grassy weeds benefited more than broadleaves.
- Group 1 products were most sensitive to all application variables, responding to rate 88% of the time, to spray quality 50% of the time, and to air induction 13% of the time.

Future studies should therefore focus on ways to improve Group 1 performance with application variables.

- Broadleaf weeds were successfully controlled with all spray qualities at 100 L/ha. When spray quality effects occurred they were minor and did not reduce control below commercially acceptable levels. Grassy weed control was not reduced with coarse sprays, but reductions below commercially acceptable levels with very coarse sprays were possible.

Table 7: Presence (Yes) or absence (No) of statistically significant effect of herbicide rate, spray quality, or air induction for grassy and broadleaved weeds, 2000.

	Effect																								
	Herbicide Rate							Spray Quality							Air Induction										
Product	AVEFA	SETVI	SINAR	POLCO	AMARE	GALAP	Lentils	AVEFA	SETVI	SINAR	POLCO	AMARE	GALAP	Lentils	AVEFA	SETVI	SINAR	POLCO	AMARE	GALAP	Lentils				
Horizon	Yes	Yes						Yes	Yes						Yes	No									
Dyvel				Yes	Yes						No	No						No	No						
Freedom				No	No						No	No						No	No						
Assure II	No	Yes						No	No						No	No									
Everest	No							No							No										
Buctril M			No	Yes	No					No	No	No					No	No	No						
Avenge	No							No							No										
Pardner			No	No	No					No	No	No					No	No	No						
Roundup	No		Yes	Yes	Yes			No		No	No	No			No		No	No	No						
Rustler	No		Yes	Yes	Yes			No		No	No	No			No		No	No	No						
Sundance	Yes		No	No	Yes			No		No	No	No			No		No	No	No						
Accord		Yes				No			No				No			No				No					
Liberty	No		No	No	No			Yes		No	No	No			No		No	No	No						
Reglone Pro							Yes							No							No				
Frequency	0.25	1.00	0.33	0.50	0.50	0.00	1.00	0.25	0.33	0.00	0.00	0.00	0.00	0.00	0.125	0.00	0.00	0.00	0.00	0.00	0.00				
	0.45		0.46					0.27		0.00					0.09		0.00								
	0.46							0.09							0.03										

*Bayer codes for weeds: AVEFA, wild oats; SETVI, green foxtail; SINAR, wild mustard; POLCO, wild buckwheat; AMARE, red root pigweed; GALAP, cleavers.

Table 8: Presence (Yes) or absence (No) of statistically significant effect of herbicide rate, spray quality, or air induction for grassy and broadleaved weeds, 2001.

	Effect																	
	Herbicide Rate						Spray Quality						Air Induction					
Product	AVEFA	SINAR	POLCO	CHEAL	GALAP	Lentils	AVEFA	SINAR	POLCO	CHEAL	GALAP	Lentils	AVEFA	SINAR	POLCO	CHEAL	GALAP	Lentils
Horizon	Yes						Yes						No					
Assure II	Yes						Yes						No					
Sundance	Yes	No	Yes				Yes	No	No				No	No	No			
Everest	Yes			No			No			No			No			No		
Freedom		Yes	Yes					Yes	Yes					No	No			
Accord					Yes						No						No	
Dyvel		Yes	Yes					No	No					No	No			
Buctril M		No		No				No		No				No		No		
Pardner		Yes						Yes						No				
Avenge	Yes						No						No					
Roundup												Yes						No
Rustler						No						No						No
Liberty	No	No	No				Yes	No	No					No	No			
Reglone Pro						Yes						No						No
Average Frequency	0.83	0.50	0.75	0.00	1.00	0.67	0.67	0.33	0.25	0.00	0.00	0.33	0.17	0.00	0.00	0.00	0.00	0.00
	0.83	0.56					0.67	0.25					0.17	0.00				
	0.64						0.36						0.05					

*Bayer codes for weeds: AVEFA, wild oats; SINAR, wild mustard; POLCO, wild buckwheat; CHEAL, lambsquarters; GALAP, cleavers.

Table 9: Presence (Yes) or absence (No) of statistically significant effect of herbicide rate, spray quality, or air induction for grassy and broadleaved weeds, 2002.

	Effect																								
	Herbicide Rate							Spray Quality							Air Induction										
Product	AVEFA	SETVI	SINAR	POLCO	AMARE	CHEAL	Lentils	AVEFA	SETVI	SINAR	POLCO	AMARE	CHEAL	Lentils	AVEFA	SETVI	SINAR	POLCO	AMARE	CHEAL	Lentils				
Horizon	Yes							No							No										
Dyvel					Yes	No						No	No						Yes	No					
Freedom					Yes	No						Yes	No						Yes	No					
Assure II	Yes							No							No										
Roundup							Yes							No							Yes				
Rustler							Yes														No				
Liberty	Yes	Yes	No	Yes	Yes			No	No	No	No	No			No	No	No	No	No						
Reglone Pro							Yes							No							No				
Frequency	1.00	1.00	0.00	1.00	1.00	0.00	1.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.67	0.00	0.33				
	1.00				0.70			0.00				0.07			0.00				0.30						
	0.79							0.07							0.21										

*Bayer codes for weeds: AVEFA, wild oats; SETVI, green foxtail; SINAR, wild mustard; POLCO, wild buckwheat; AMARE, redroot pigweed; CHEAL, lambsquarters.

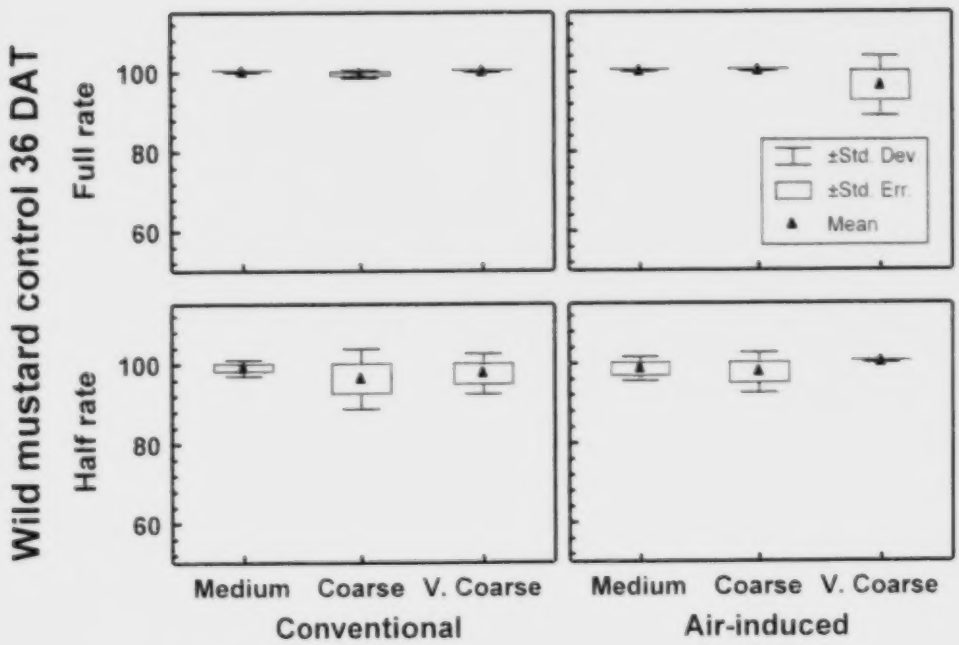

Figure 3: Effect of herbicide rate and application method on Horizon/Dyvel efficacy on wild mustard, 2000.

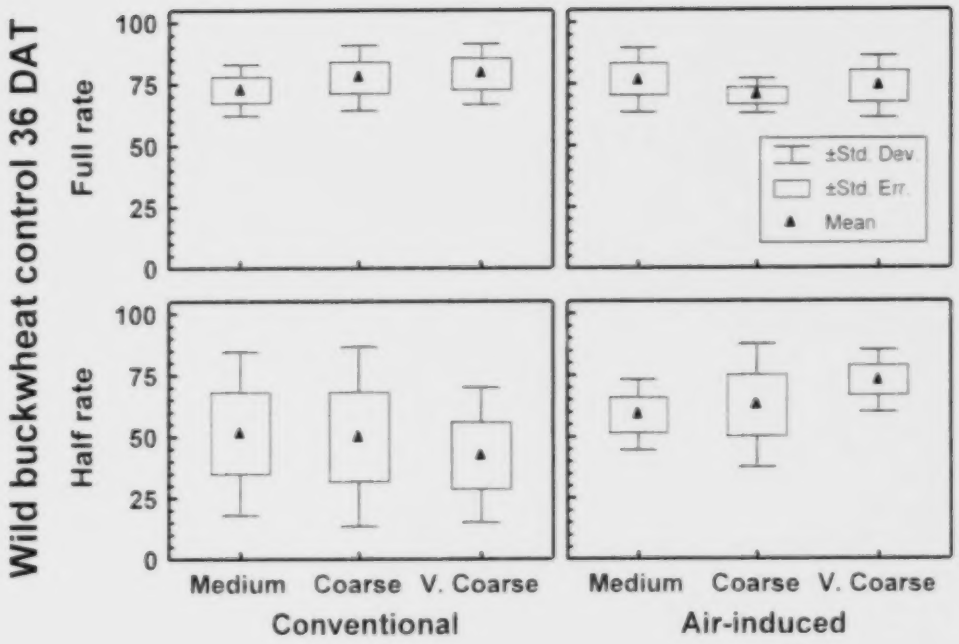

Figure 4: Effect of herbicide rate and application method on Horizon/Dyvel efficacy on wild buckwheat, 2000.

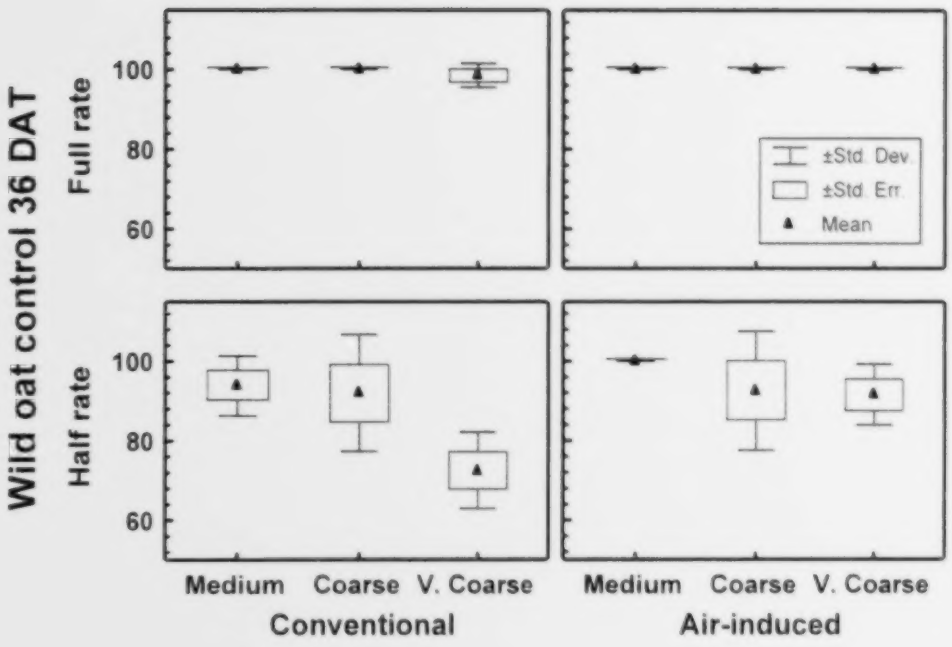

Figure 5: Effect of herbicide rate and application method on Horizon/Dyvel efficacy on wild oats, 2000.

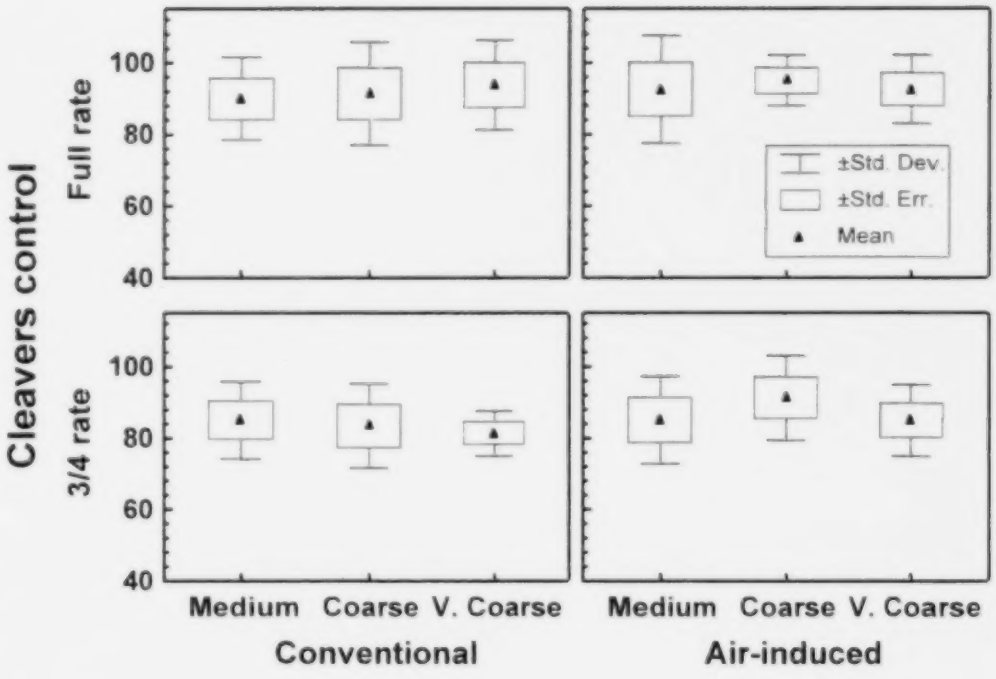

Figure 6: Effect of herbicide rate, spray quality, and air induction on Accord efficacy on cleavers, 2001.

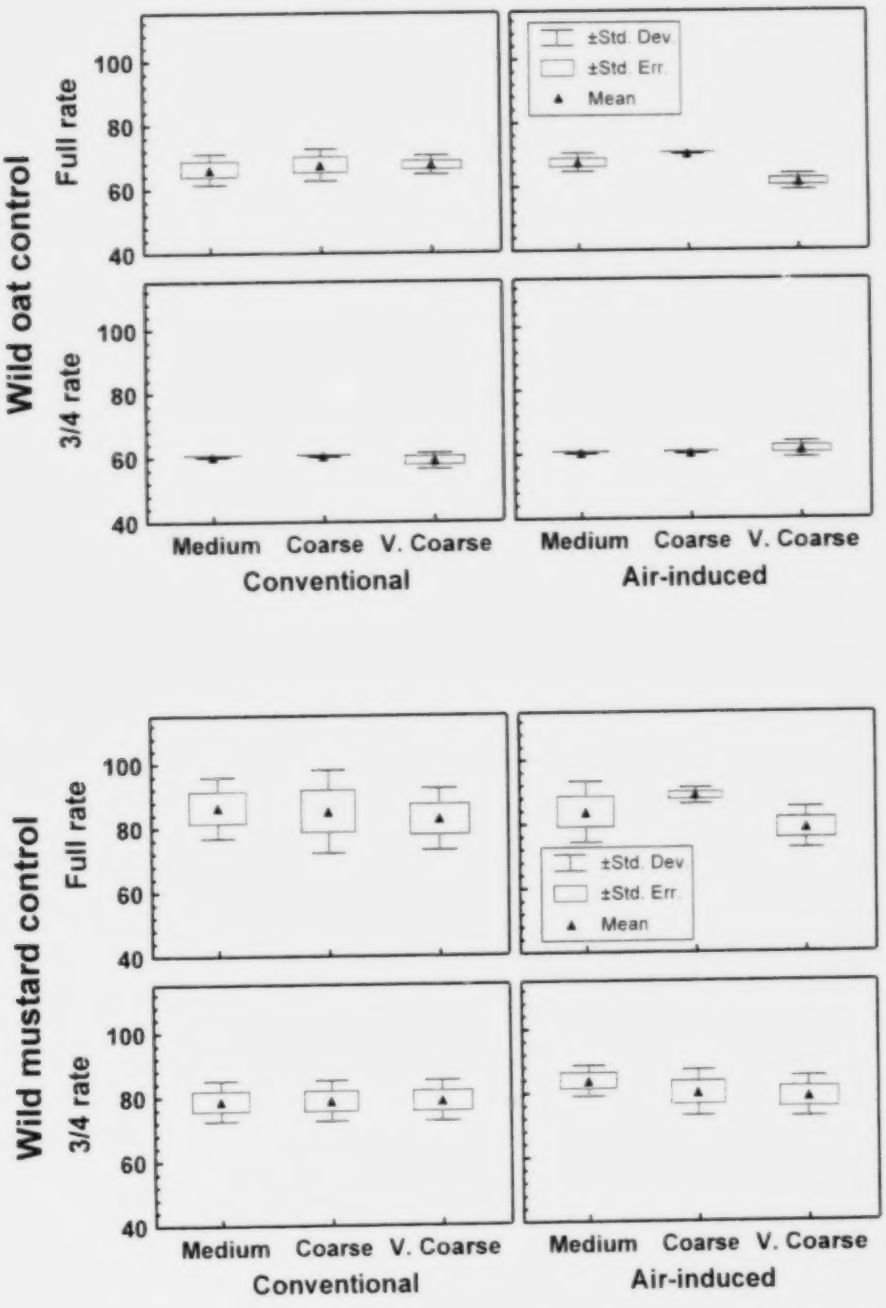

Figure 7: Effect of herbicide rate, spray quality, and air induction on Avenge/Pardner efficacy on wild oats (top) and wild mustard (bottom), 2001.

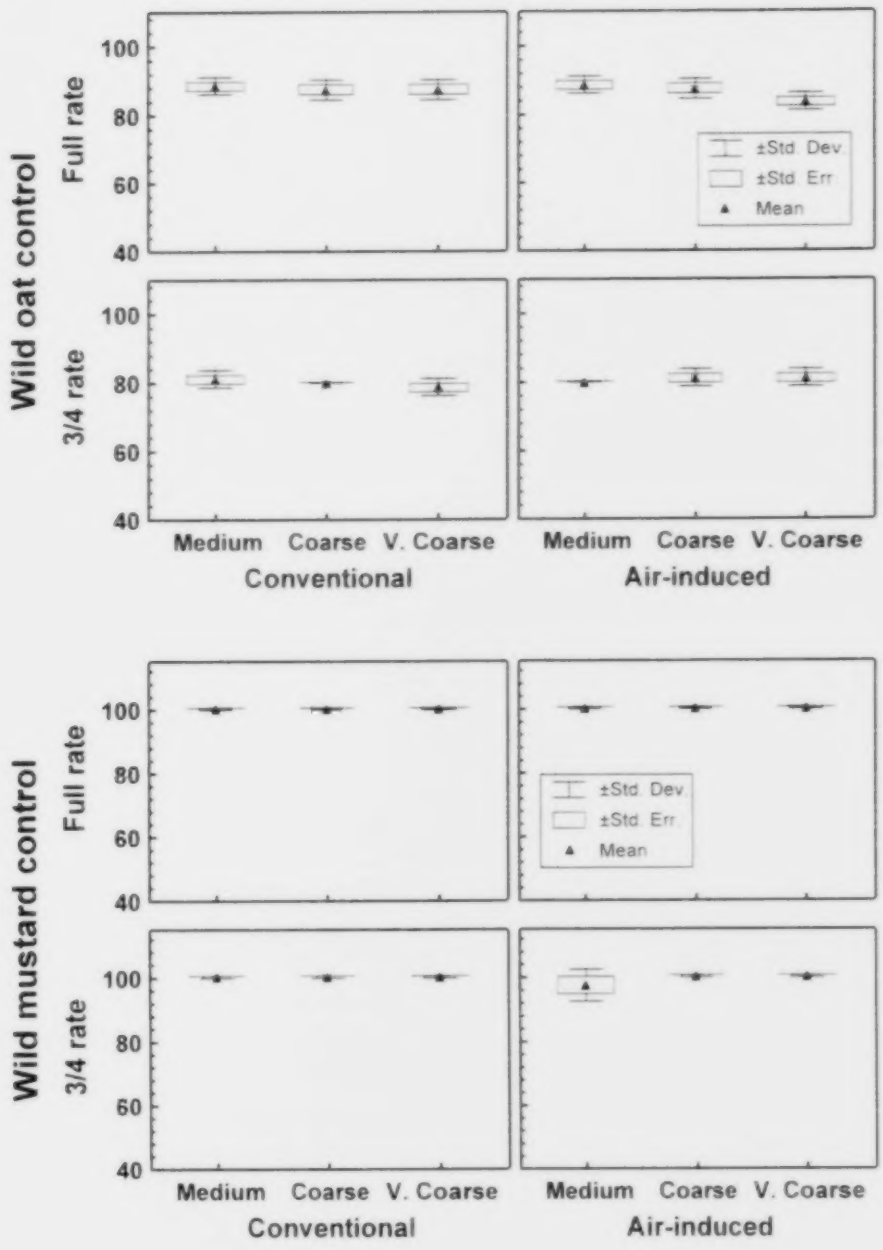

Figure 8: Effect of herbicide rate, spray quality, and air induction on Everest efficacy on wild oat (top) and wild mustard (bottom), 2001.

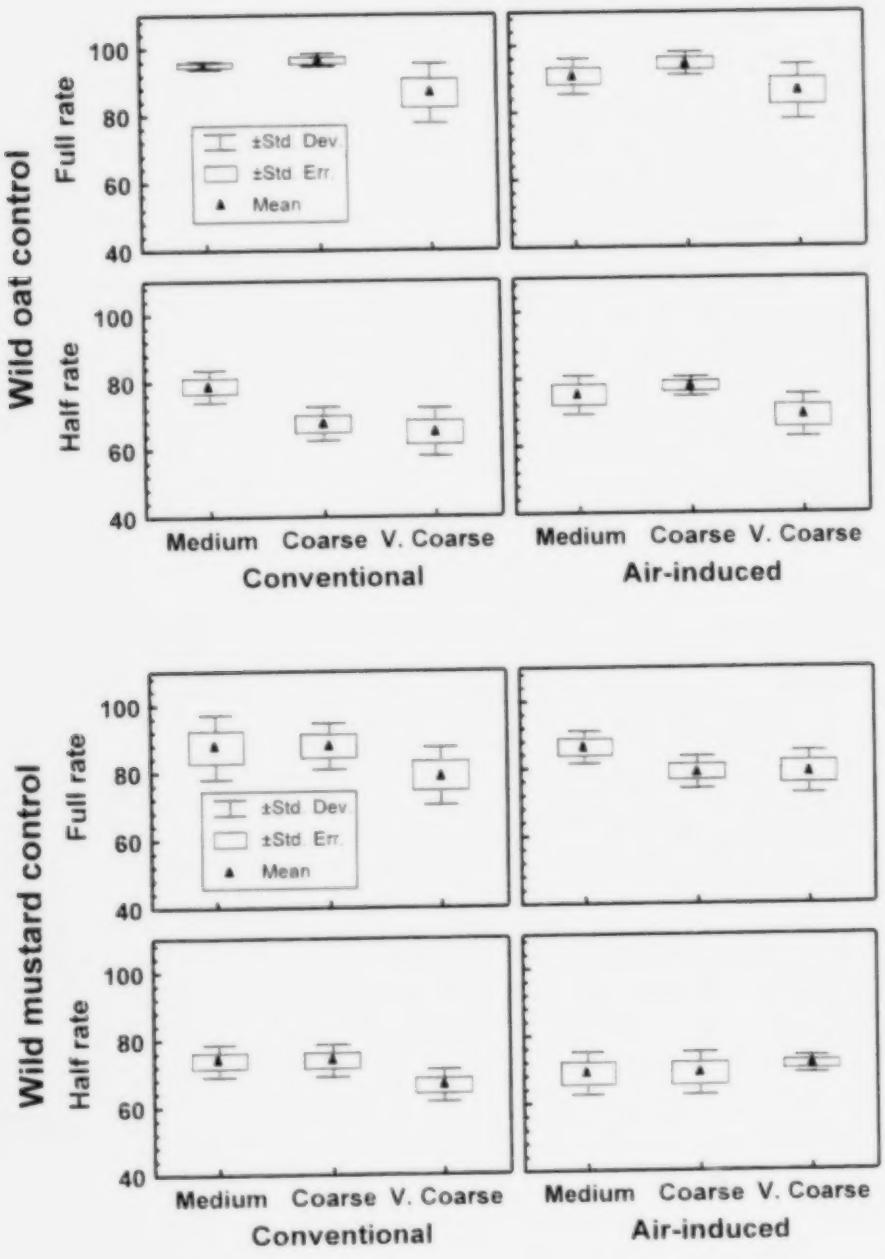

Figure 9: Effect of herbicide rate, spray quality, and air induction on Freedom Gold efficacy on wild oat (top) and wild mustard (bottom), 2001.

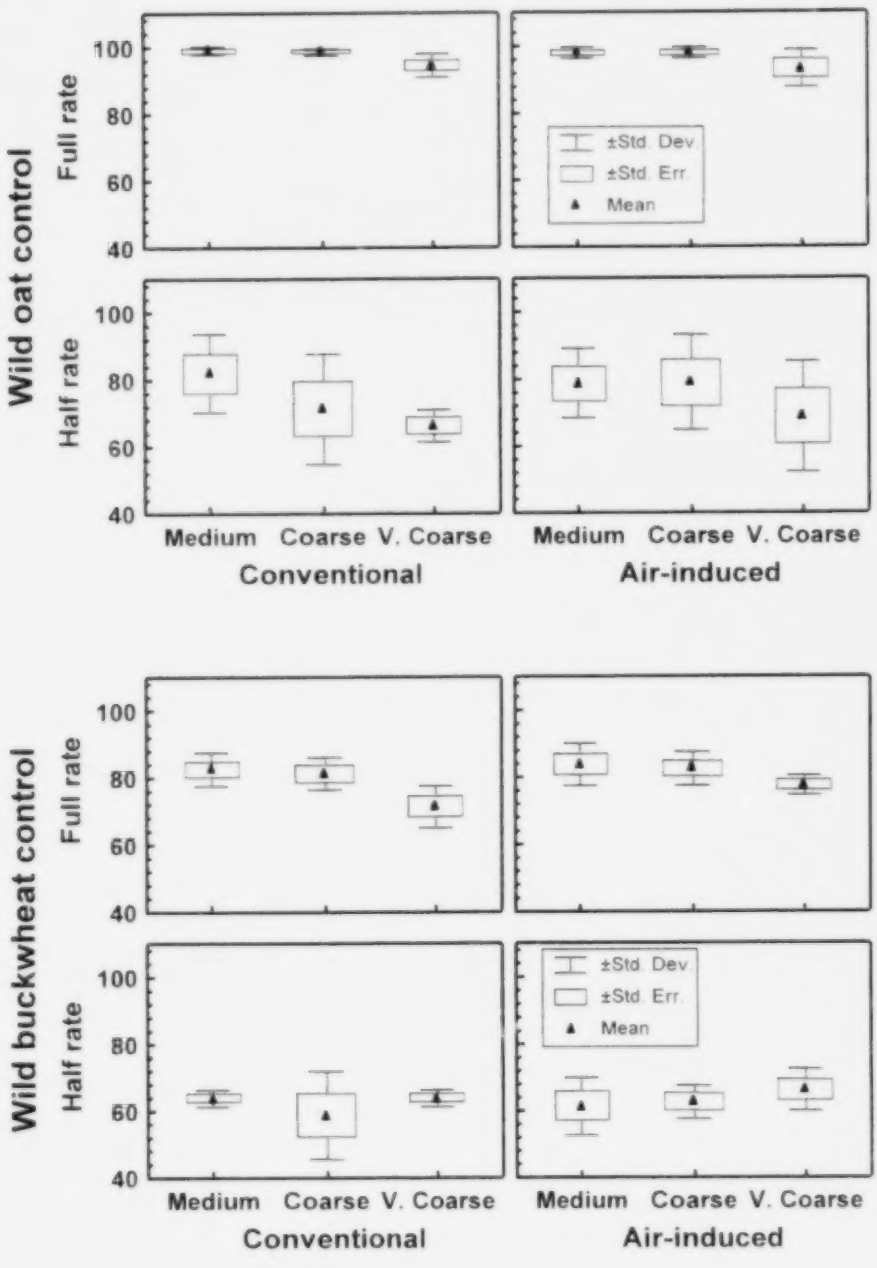

Figure 10: Effect of herbicide rate, spray quality, and air induction on Horizon / Dyvel efficacy on wild oat (top and wild buckwheat (bottom), 2001.

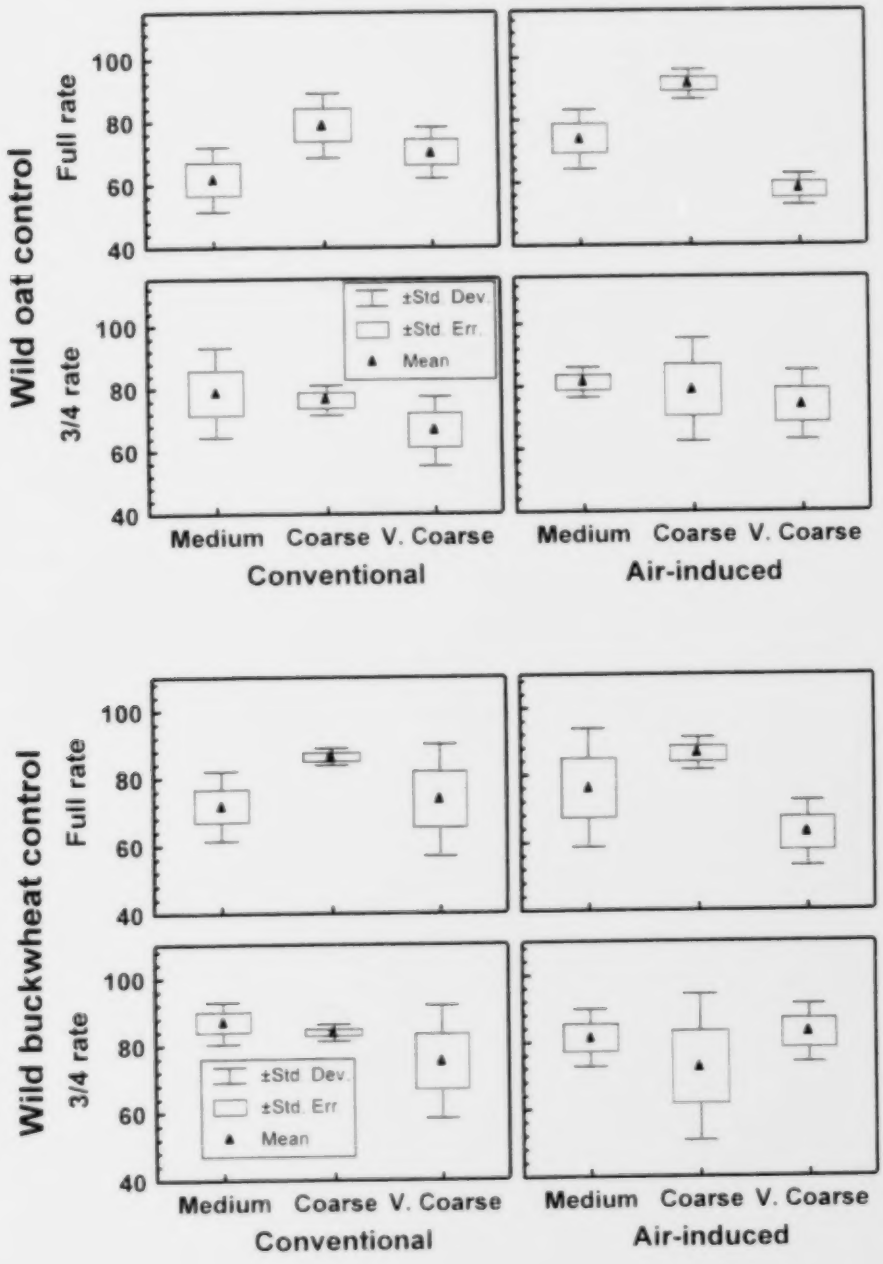

Figure 11: Effect of herbicide rate, spray quality, and air induction on Liberty efficacy on wild oat (top) and wild buckwheat (bottom), 2001.

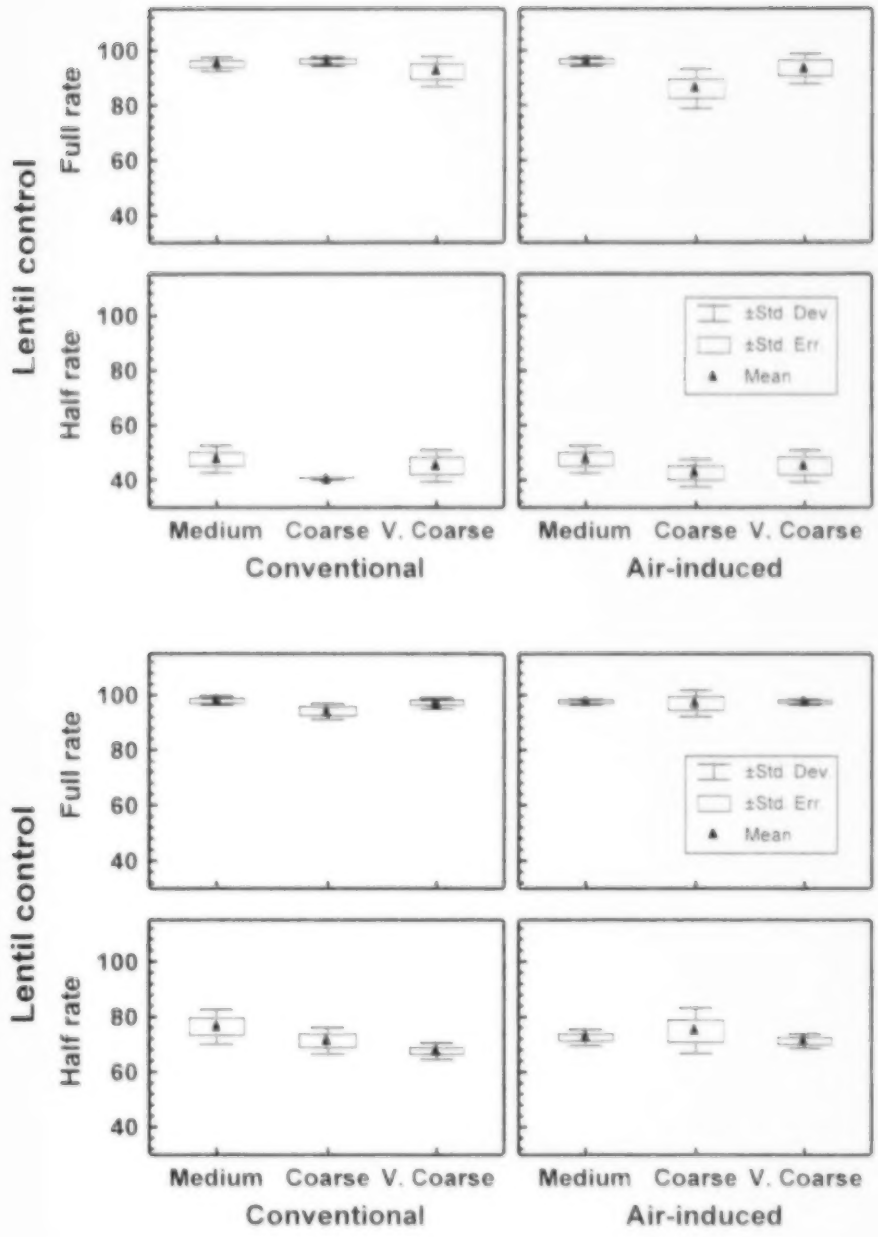

Figure 12: Effect of herbicide rate, spray quality, and air induction on Roundup (top) and Rustler (bottom) efficacy on volunteer lentil, 2001.

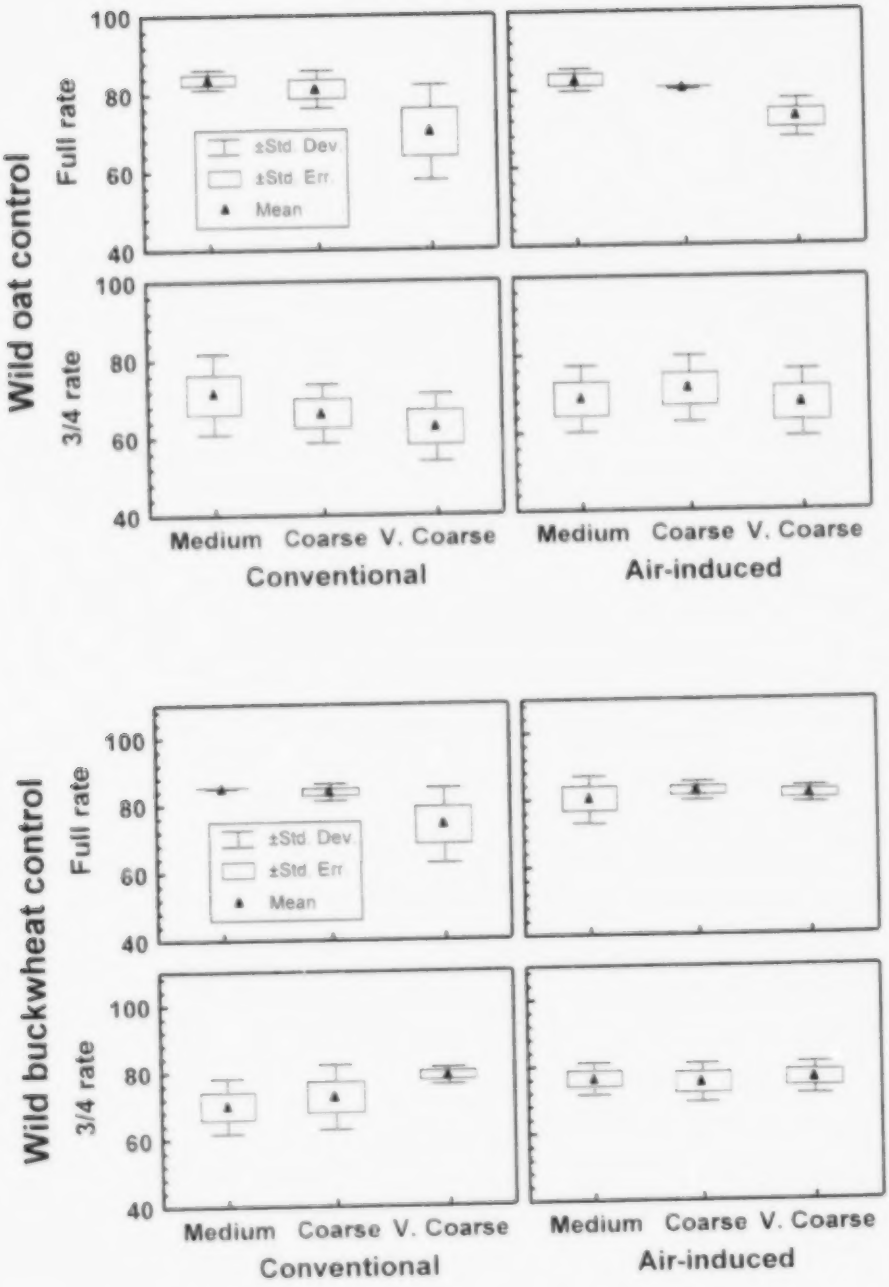

Figure 13: Effect of herbicide rate, spray quality, and air induction on Sundance efficacy on wild oats(top) and wild buckwheat (bottom), 2001.

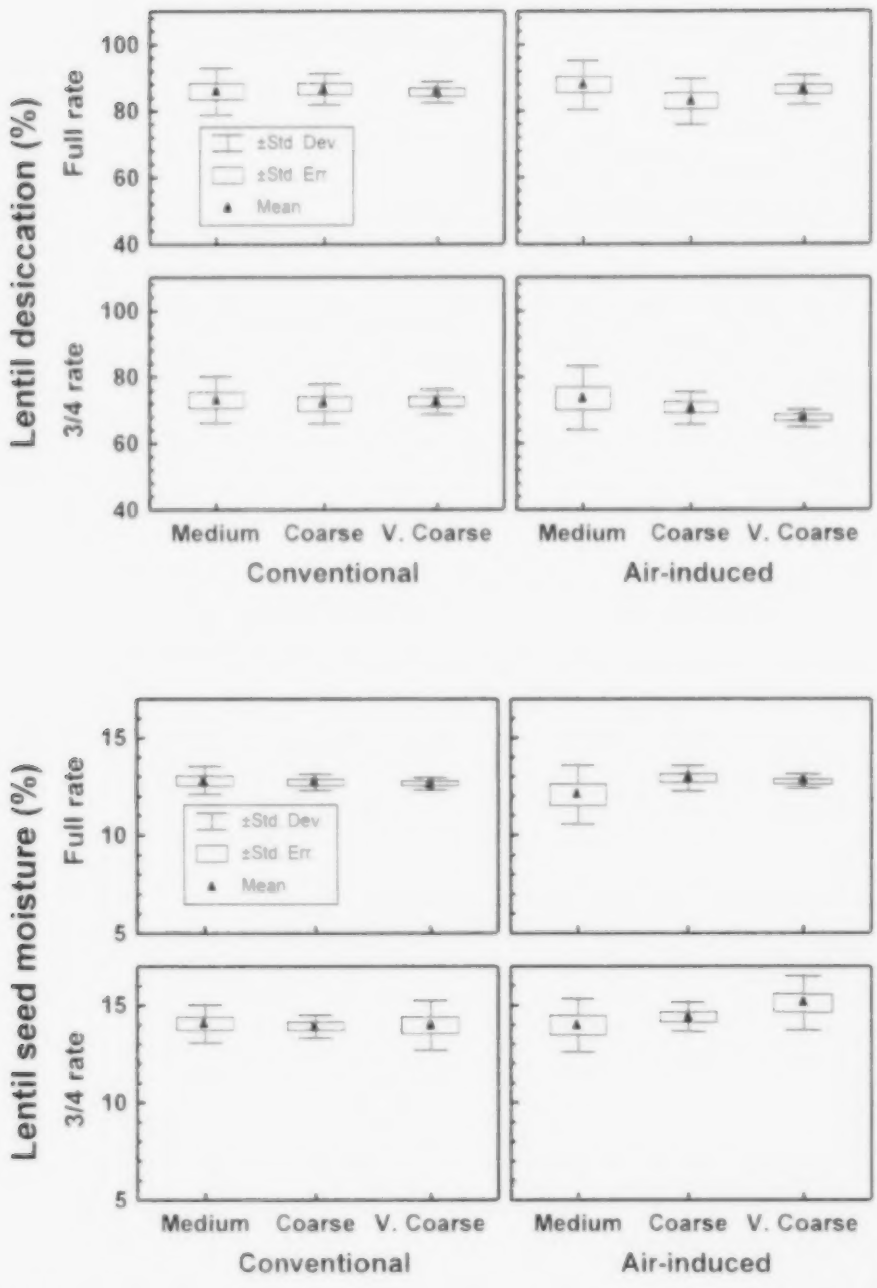

Figure 14: Effect of herbicide rate, spray quality, and air induction on Reglone lentil desiccation (top) and seed moisture (bottom), 2001.

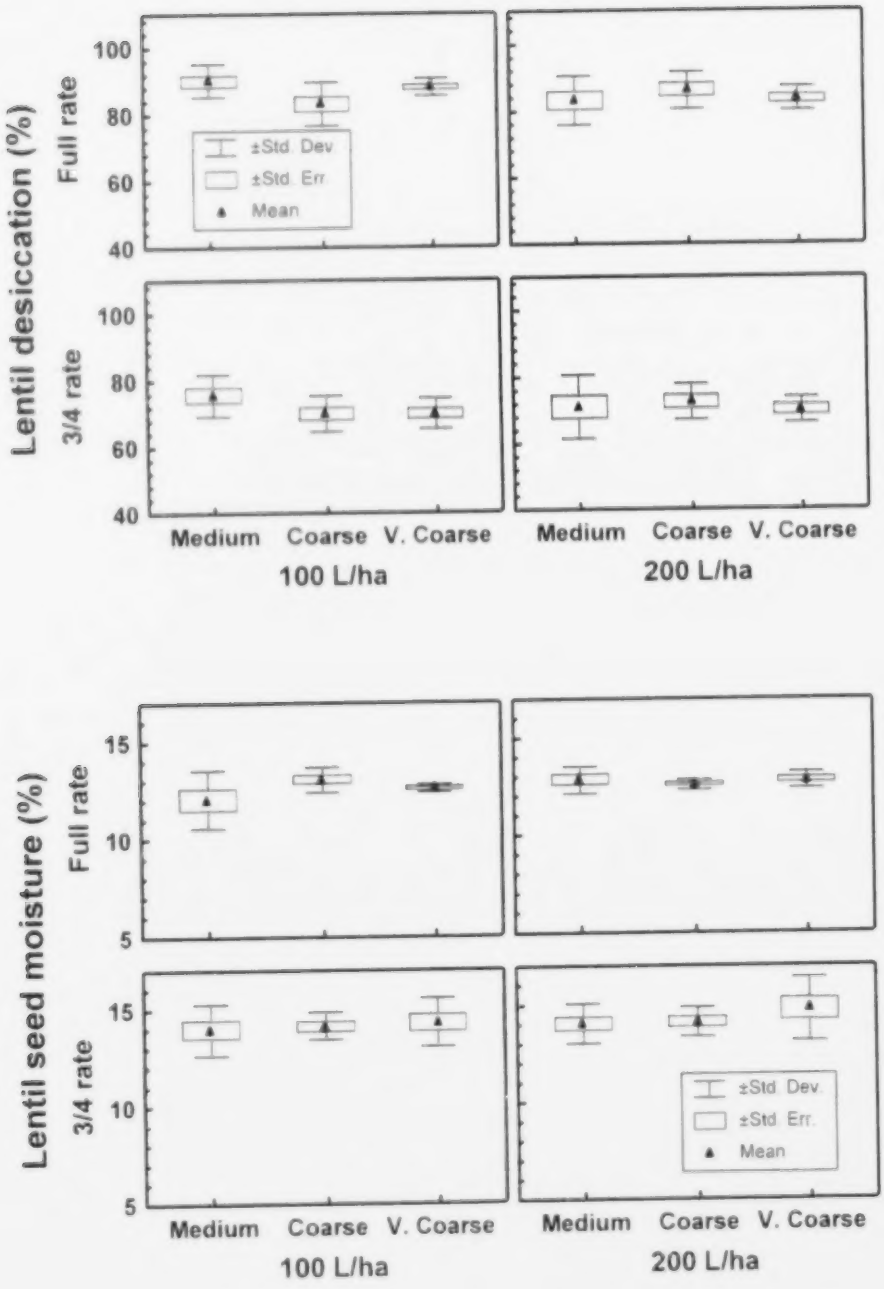

Figure 15: Effect of herbicide rate, spray quality, and water volume on Reglone lentil desiccation (top) and seed moisture (bottom), 2001.

LABORATORY STUDIES

Background

Air Induction

Large droplets which contain air inclusions reduce spray drift and are also claimed to reduce reflection from leaf surfaces. This can be explained as follows: for a droplet of a given diameter (say 500 µm), air inclusions will increase the drop diameter, but not its mass. It will therefore travel more slowly (due to increased drag), reducing its kinetic energy. Upon impact with a target, the air inclusions make the droplet less stable, increasing its likelihood of shattering. A shattered droplet can leave a deposit which resembles the deposit of several smaller droplets. Air induction can therefore reduce drift potential without increasing reflection from the target.

Target Characteristics

Leaf angle can have a significant effect on surface retention of pesticides (Wolf et al., 2000). Planophile plants, or species that have leaves approximately parallel to the grounds surface and thus low leaf angles, retain greater amounts of spray. Erectophile plants, which are characteristic of high leaf angles, such as grasses, often have lower interception and retention of herbicides (Spillman, 1984). These losses tend to be significant with hard to wet surfaces. Although species specific, leaf orientation has been found to change towards the horizontal with increasing leaf age (Jensen and Kirknel, 1994). Additionally, Jensen et al. (1994) showed significantly lower deposition on younger growth stages. This effect is particularly significant with very coarse droplets. Young growth stages appear to be smooth in texture thus increasing the probability of repulsion (Spillman, 1984). Older leaf surfaces, are rougher in texture and offer a greater possibility of droplet capture. These effects need to be balanced with the general observation that more mature plants are also more difficult to control.

Leaf surface properties are important in determining spray retention. Leaf hairs and wax can limit the amount of herbicide that can diffuse quickly into the epidermal layers of the plant, thus reducing control (Jensen and Kirknel, 1994). Complex crystalline leaf surfaces are typically difficult to wet (Harr et al., 1991). Difficult-to-wet species have been found to have contact angles of water droplets >110 degrees, whereas easy-to-wet surfaces are characterized by contact angles <110 degrees (Knoche, 1994). Thus, herbicides are able to spread more quickly on easy-to-wet surfaces. Generally, larger droplets are easily retained on easy-to-wet broadleaved species while difficult-to-wet grasses tend to repel such droplets (Wolf et al., 2000).

Examples of difficult-to-wet surfaces include *Avena fatua* and *Hordeum vulgare*, while easy-to-wet surfaces include *Sinapsis alba* and *Polygonum spp.* (Harr et al., 1991).

Materials and Methods

Nozzles

Three spray qualities (medium, coarse and very coarse) were applied using conventional flat fan and air-included tips, identical to those in the field studies (Figure 1). Spray qualities are intended only to differentiate nozzles in a generic manner, and only approximately reflect ASAE quality classification. Nozzles included in this study were:

1. Non-air induced standard and pre-orifice flat fans at 40 psi
   - Wilger ER8002 (medium spray)
   - Delavan RF8002 (coarse spray)
   - Wilger DR8002/04 (very coarse spray)
2. Air-induced tips, each at about 70 psi, delivering the equivalent to an 8002 at 40 psi.
   - Air Bubble Jet 110015 (medium spray)
   - TurboDrop 110015 (coarse spray)
   - Delavan Raindrop Ultra 110015 (very coarse spray)

Nominal flow rates were lower, and spray pressures were higher, for the air-induced tip to be consistent with current recommendations for optimum efficacy, and also to more closely match spray deposits of paired nozzles (Figure 2). In-flight spray droplet sizes for each nozzle were determined on a Phase / Doppler Particle Analyzer, using a traverse scan along the x-axis (mean droplet size) and using y-axis traverses at 5-cm increments to document changes in spray characteristics along the x-axis. Nozzles were calibrated by collecting output for 30 seconds from each nozzle. Pressures were adjusted as needed to ensure that all nozzles had equivalent output so that a single travel speed could be used (Table 10).

Spray Mixture

Spray was applied to three simulated weed species: tame buckwheat, tame oats and oriental mustard. Target water volume was 100 L/ha. The spray mixture included a fluorescent tracer dye (Rhodamine WT) at 2 ml / L (2000 ppm) and a non-ionic surfactant (Agral 90) at 0.1 % v/v.

Sprayer Set-up

Treatments were applied in a 15-m long track room using a five nozzle hydraulic boom. Nozzle spacing was 50 cm with a boom height of 50 cm above mean target height. Boom travel speed was 8.9 km/hr (Table 10).

Table 10. Experimental treatment volumes, operating pressures and speed of application.

Nozzle	Volume (L/ha)	Pressure (psi)	Speed (km/h)
ER8002	100	39	8.9
RF8002	100	40	8.9
DR8002/04	100	38	8.9
ABJ110015	100	67	8.9
TD110015	100	64	8.9
Delavan RD Ultra	100	73	8.9

Targets

Three simulated weed species, oriental mustard, tame buckwheat and tame oats, were used in this retention study. Plant species were placed both under the centre of the middle nozzle and under the overlap of this nozzle and its adjacent nozzle (25 cm beside the first location), to identify any change in patternation. Four replicates were sprayed per treatment and each replicate was sprayed with a separate pass of the sprayer. Petri dishes were placed in the same locations, one under the centre of the nozzle and one under the overlap, during each treatment and replicate, to monitor sprayer output at each plant location.

Plant Material

All plants were grown in conetainers in a greenhouse with a 16 hr daylength. The soil was a commercial greenhouse mix, which contained slow-release fertilizer. Plants were watered as needed for seedling establishment and healthy plant growth. The plants were used 19-21 days after sowing when the mustard had 2-3 leaves, the buckwheat had 1-2 true leaves and the tame oats had 2 – 3 leaves.

Deposit Quantification

Immediately after spraying, plants and petri-dishes were removed from the track room. Plants were clipped at ground level and placed in a container containing 100 mL 95% ethanol, and agitated for 60 s. This rinse method had recoveries of greater than 95%, determined separately. Plants were removed from ethanol, placed in paper bags, and dried at 80° C for 48 h. Petri plates were rinsed three times with 15 mL of ethanol, and the volume was made up to 50 mL. All washes were sub-sampled and stored in the dark in 20 mL borosilicate vials. Within 24 h, samples were analyzed on a fluorescence spectrophotometer. Tracer quantity in each

sample was determined from standard curves. Deposit amounts were adjusted for spray delivery (petri plate data) and plant dry weight, expressed as µL/g dry wt.

Results

Laser Droplet Size Analysis

Although spray qualities were not identical, they represented a reasonably close match. On the average, air-induced sprays were coarser than their no-induced counterparts, except for the Greenleaf TurboDrop, which was slightly finer than the Delavan RF (Table 11).

Table 11: Spray droplet parameters of nozzles used in study.

Nozzle	Pressure (psi)	Droplets Counted	$D_{V0.5}$ (µm)	% Volume <100 µm	Velocity (m/s)
ER8002	40	29231	199	9.24	3.70
RF8002	40	7856	332	3.42	2.05
DR8002	40	5524	431	1.45	2.61
Air Bubble Jet 015	60	12948	259	5.42	2.63
Greenleaf Turbodrop 015	60	10278	313	3.30	2.59
Spray Master Ultra 015	60	2964	556	0.72	2.53

Droplet size and number distributions under the spray fan are shown in Figure 16. Droplet numbers were highest directly under the nozzle, and diminished towards the edge of the fan. At the higher pressure, droplet numbers increased but spatial trends were similar. There were significant differences in overall droplet numbers between nozzles. For example, the Air Bubble Jet at 60 psi had only about one third of the total droplet numbers compared to the ComboJet ER at 40 psi (i.e., the same flow rate) under the nozzle, but similar numbers at the fan edges. Coarser sprays had lower droplet numbers, as expected, but the Delavan RF and the Greenleaf TurboDrop were had comparable numbers. The Delavan (SprayMaster) Raindrop Ultra had the lowest droplet numbers, and these remained low even directly under the nozzle and at higher pressures, where the other nozzles experienced a rise in droplet number.

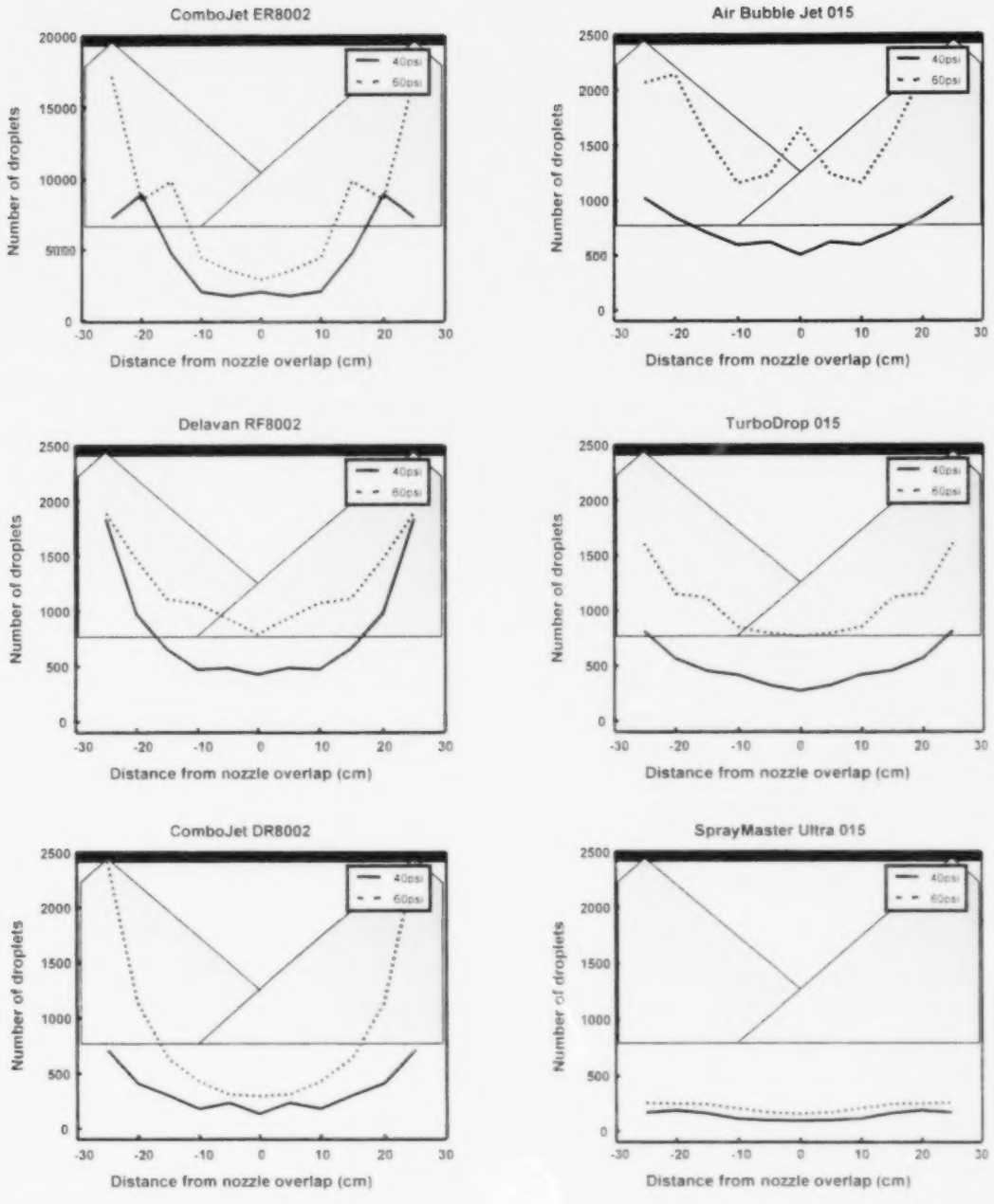

Figure 16: Droplet density along spray pattern. 0 cm defines the centre of the overlap of two adjacent nozzles. 35 cm defines the centre of each nozzle.

Spray Retention

Analysis of Variance indicated that spray quality, air induction, and location interacted with each other for both broadleaf species (Table 12 and Table 13). For tame oats, only the spray quality effect was significant (Table 14).

Table 12: Summary of ANOVA for spray retention on oriental mustard.

Effect	df Effect	MS Effect	df Error	MS Error	F-Value	p-level
Quality	2	2641	33	765	3.45	0.043 *
Air	1	25536	33	765	33.39	<0.001 **
Location	1	108	33	765	0.14	0.710 ns
Quality*Air	2	2799	33	765	3.66	0.037 *
Quality*Location	2	7708	33	765	10.08	<0.001 **
Air*Location	1	4957	33	765	6.48	0.016 *
Quality*Air*Location	2	5793	33	765	7.57	0.002 **

Table 13: Summary of ANOVA for spray retention on tame buckwheat.

Effect	df Effect	MS Effect	df Error	MS Error	F-Value	p-level
Quality	2	478	33	1509	0.32	0.731
Air	1	7274	33	1509	4.82	0.035
Location	1	30	33	1509	0.02	0.888
Quality*Air	2	1761	33	1509	1.17	0.324
Quality*Location	2	13764	33	1509	9.12	0.001
Air*Location	1	2677	33	1509	1.77	0.192
Quality*Air*Location	2	4959	33	1509	3.29	0.050

Table 14: Summary of ANOVA for spray retention on tame oats.

Effect	df Effect	MS Effect	df Error	MS Error	F-Value	p-level
Quality	2	4194	33	183	22.91	<0.001 **
Air	1	146	33	183	0.80	0.378
Location	1	95	33	183	0.52	0.475
Quality*Air	2	314	33	183	1.72	0.195
Quality*Location	2	309	33	183	1.69	0.201
Air*Location	1	86	33	183	0.47	0.498
Quality*Air*Location	2	25	33	183	0.14	0.871

Weed Species Effect on Plant Retention

Weed species had a significant effect on spray retention although this was not tested explicitly. Spray retention values indicate that the broadleaf species retained between six and seven times as much product compared to the grassy species on a dry weight basis when averaged over all application methods (Figure 17). This indicates that grassy species represent challenging targets, ones where overall spray dosages are smaller and likely more difficult to achieve than for broadleaf species. Air induction tended to increase retention on broadleaf species but had no overall effect on the grassy species.

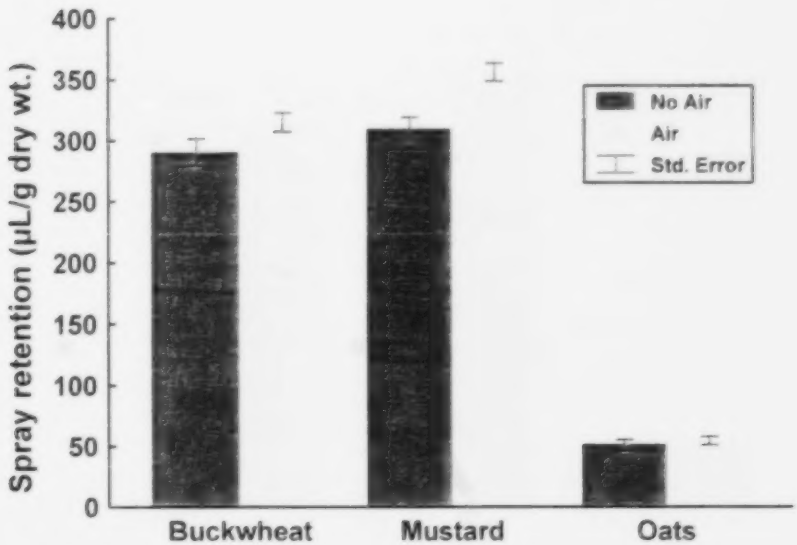

Figure 17: Variation in amount of spray retained on three different target species with and without air induction.

Spray Quality, Air Induction and Location Interactions

The ANOVA indicated significant interactions between spray quality, air induction, and location under the nozzle for the broadleaf species. For consistency, oat data will also be presented in a similar format to facilitate comparisons.

Tame Buckwheat

As suggested by ANOVA, the effect of spray quality depended on location and air induction. Without air induction, spray quality had pronounced effects on retention that depended on location (Figure 18). Under the nozzle centre, coarser sprays increased retention. Under the nozzle overlap, they decreased retention. With air induction, the effect of spray

quality was moderated, becoming insignificant under the nozzle centre. Under the overlap, there was a slight but statistically insignificant decrease in retention with the two coarser sprays. It is possible that changes in the spray quality under the overlap were responsible for the location effect.

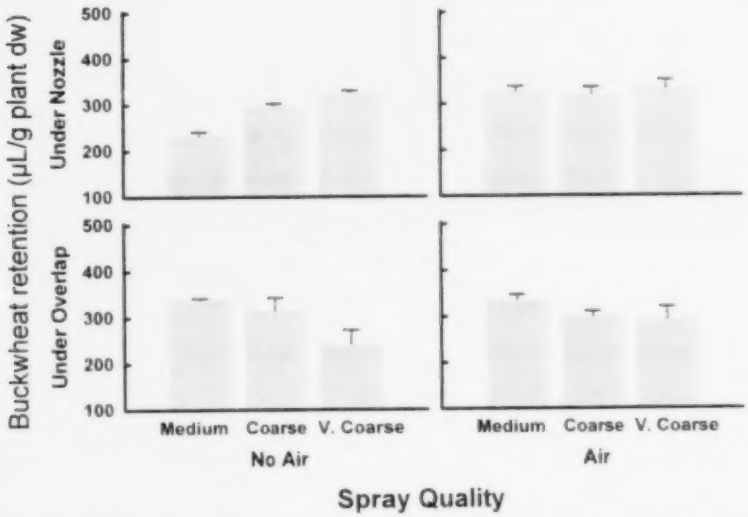

Figure 18: Effects of spray quality, air induction and location interactions on tame buckwheat spray retention (means ± standard error)

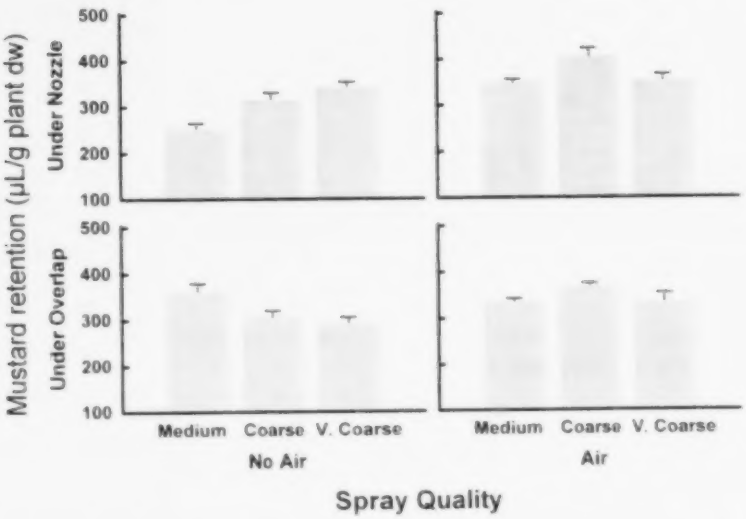

Figure 19: Effects of spray quality, air induction and location interactions on oriental mustard spray retention (means ± standard error).

Oriental Mustard

Results for oriental mustard were similar to those for tame buckwheat: spray quality was more important for conventional than for air-induced sprays (Figure 19). As previously, the effect of spray quality depended on location with conventional sprays. Under the nozzle centre, greater retention was achieved with coarser spray qualities, whereas the opposite was true under the nozzle overlap. With air induction, the location effect was not significant, and the coarse spray tended to provide the best retention.

Tame Oats

Spray quality had a significant effect on spray retention regardless of location or air induction (Figure 20). With conventional nozzles, the medium spray quality provided the best retention at both locations. With air induction, the medium and coarse spray qualities provided equivalent retention values, superior to the very coarse quality. These results suggest that although air-induction had not significant effect overall, it did permit a coarser spray to be applied without loss of retention compared to the conventional sprays.

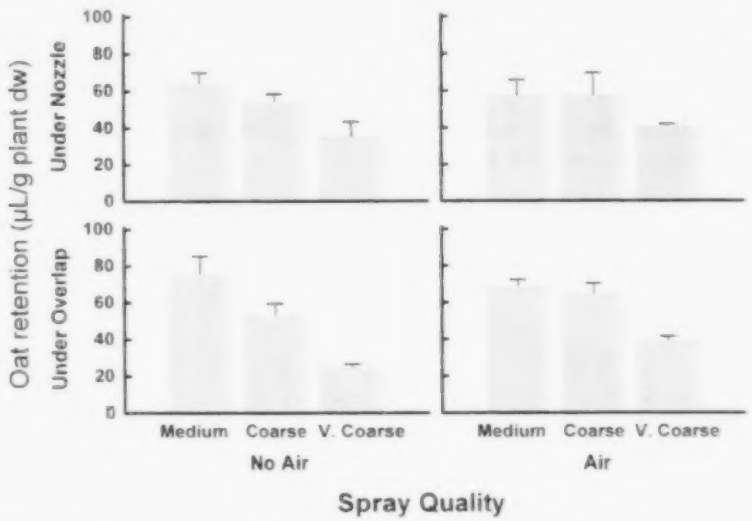

Figure 20: Effects of spray quality, air induction and location interactions on tame oat spray retention (means ± standard error).

Conclusion

- Tame buckwheat and oriental mustard tended to retain between 6 and 7 times more spray on a dry weight basis than tame oats;

- Coarser sprays reduced retention on tame oats, but were neutral or tended to increase spray retention on the broadleaf species;
- Overall, air induction increased spray retention on broadleaf species but had no effect on oats. Air induced sprays had more uniform patterns than conventional sprays;
- For the broadleaf species, spray quality and air induction interacted with location. The presence of air induction reduced the effect of both location and spray quality, providing more uniform retention values within treatments;
- For oats, there was a significant reduction in retention with an increase in droplet size for the non-induced sprays, whereas the air-induced sprays maintained a higher level of retention as spray quality became coarser.
- On the whole, low-drift sprays demonstrated equivalent or better spray retention than conventional flat fan sprays. For broadleaf weeds, very coarse sprays could be used successfully with air induction. Very coarse sprays should not be used on grassy weeds. On oats, air induction facilitated the use of coarse sprays which would otherwise reduce retention values.

Acknowledgements:

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Project Activities and Achievements

There has been continued interest in this work from producers, industry, and extension specialists, resulting in many presentations and phone calls from throughout western Canada, Ontario, as well as north and central US. We have extended results of our work to SAF staff, including the new Knowledge Centre.

Presentations, Posters, and Tours:

1. "Technology and Project Update". CPI Saskatchewan Technical Committee, Saskatoon, SK, April 4, 2000 (20 people).
2. "Improving Industrial Weed Control Through Nozzle Selection". Manitoba Weed Supervisors Annual Conference, Russell, MB, April 6, 2000 (60 people).

3. BASF national staff and summer students, May 4, 2000, training in Saskatoon on sprayer calibration and spray technologies (20 people).
4. "Interpreting New Application Technology for Applicators". Spray and Seed Demo, Monsanto, Brandon, MB, June 28 and 29, 2000 (150 people).
5. "What's New with Sprayer Technology" Ontario South Western Crop Diagnostic Day, July 4 and 5, 2000 (24 talks given over two days to 400 people) (
6. James Richardson International (Pioneer Grain) eastern Canadian Agrologists on use of low-drift nozzles on high clearance sprayers, recommendations for specific herbicides, etc. Winnipeg, MB, July 12, 2000 (30 people).
7. Scott Field Day, plot and sprayer demonstration, July 19, 2000 (field demo) (200 people).
8. Saskatchewan Weed Tour, Scott SK, July 20, 2000 (field demo) (70 people).
9. Lashburn Field Day, July 26, 2000 (sprayer demo) (70 people).
10. Application Technology – What's New, What Works. Southwest Ontario Ag Conference, Ridgetown, ON, January 3 and 4, 2001 (100 people).
11. "Low Drift Nozzles: How Coarse Can You Go?" Crop Production Show , Saskatoon, January 9, 2001 (100 people).
12. "New Developments in Spray Technology". 29th Saskatchewan Alfalfa Seed Conference Saskatoon, SK, Jan. 12, 2001 (75 people).
13. "Pesticides: Minimizing Environmental Impacts". FarmTech 2001 Conference, Red Deer, AB, Jan. 31 - Feb. 2, 2001 (50 people).
14. "Low Drift Nozzles: How Coarse Can You Go?" U of S Agronomy Workshop, Saskatoon, January 21, 2001 (100 people).
15. Low-Drift Nozzles - How Coarse is Too Coarse? Tom Wolf, Ken Sapsford, and Rick Holm. Poster presented at Soils and Crops Workshop, Feb 22-23, 2001, Saskatoon, SK.
16. Application Technology clinic for Crop Diagnostic Day at U of S July 11, 2001.
17. Low-Drift Sprays - How Coarse Can You Go? U of S Agronomy Workshop, Saskatoon, SK, February 21, 2001.
18. Application Technology - Dose Transfer. Lecture and lab demo for How Herbicides Work - a course organized by Linda Hall, AAFRD, Edmonton, AB, February 23, 2001
19. Application Technology. Pioneer Coop Agronomy Days, Swift Current, SK, February 28, 2001
20. An Overview of Some Recent Research Results in Spray Technology. Swift Current Progressive Farmers Club (Stacey Wiens, organizer), Swift Current, SK, Feb 28, 2001
21. Modern Sprayer Technology. A short lecture given to SIAST Certified Applicator Training, Saskatoon, SK, March 2, 2001
22. Advanced Sprayer Issues for the Custom Applicator. Agricore Custom Applicator Training Worskshop, Calgary AB, March 6, 2001
23. Advanced Sprayer Issues for the Custom Applicator. Agricore Custom Applicator Training Workshop, Winnipeg, MB, March 20, 2001
24. Low-Drift Sprays - How Coarse Can You Go? UGG and Dow AgroSciences Agronomy Seminar, Melfort, Regina, Saskatoon, SK, March 27-29, 2001
25. Spray Efficacy Review. Research Update to PMRA staff, Ottawa, ON, April 2, 2001
26. Application Technology. Manitoba Weed Supervisors Spring Training Seminar, Russell, MB, April 5, 2001

27. Sprayer Technology for the Researcher. BASF Training Seminar, Saskatoon, SK, May 1, 2001
28. Pre-harvest Primer. Monsanto Custom Applicator Field Day, Saskatoon, SK, July 20, 2001
29. Spraying in Canada. Application Technology Course, Norre Alslev & Hjalet, Denmark, August 16, 2001
30. Spraying in Canada. Agricultural University of Sweden, Department of Agricultural Engineering, Alnarp campus, Alnarp, Sweden, August 20, 2001
31. Spraying in Canada. Agricultural University of Sweden, Department of Agricultural Engineering, Uppsala campus, Uppsala, Sweden, August 22, 2001
32. Canadian Issues on Spray Quality and Buffers. Pesticide Spray Drift B Educators' Conference, Sacramento, CA, Sept. 6, 2001
33. Spray Technology. Lecture to U of S Diploma Class, Oct. 31, 2001
34. Nozzle Technology, Product Efficacy, and Drift Management. Series of training courses for Hardi customers in London, Ridgetown, Guelph, Newmarket, and Kemptville, Ontario, Jan 21-25, 2002.
35. Sprayer Technology, Spray Drift, and Herbicide Formulation. Lectures for U of S Herbicide Biochemistry Degree students, Feb 11 & 13, 2002.
36. Sprayer Nozzles, Adjuvants, and Tank Cleanout. Laboratory presentations at U of S Agronomy Workshop, Feb 19-20, 2002.
37. Nozzle Technology, Product Efficacy, and Drift Management. DuPont Retailer meeting, Feb. 25, 2002.

Publications:

1. Wolf, T.M., Holm, F.R., Sapsford, K., Hall, L. and Van Acker, R. 2003. Interaction of spray quality, air induction, and herbicide mode of action on weed control. Proceedings of the Canadian Weed Science Society Meeting, Halifax, NS, Nov. 30-Dec. 3, 2003.
2. Wolf, T.M. 2004. Nozzle Selection Guidelines for Optimum Efficacy & Drift. Proceedings of the International Conference on Pesticide Application for Drift Management, Hilton Waikaloa Hilton Resort, Hawaii, Oct 27-29, 2004, edited by C. Ramsay, A. Hewitt, H. Thistle, C. Hoffman, R. Wolf, T. Wolf, pp. 241-245.
3. Wolf, T.M., Sapsford, K., Holm R., Hall, L. and Van Acker, R. 2004. Interactive effects of spray quality, air induction, and herbicide mode of action on weed control. Proceedings of the International Conference on Pesticide Application for Drift Management, Hilton Waikaloa Hilton Resort, Hawaii, Oct 27-29, 2004, edited by C. Ramsay, A. Hewitt, H. Thistle, C. Hoffman, R. Wolf, T. Wolf, pp. 366-369.
4. Wolf, T.M. 2002. Optimising herbicide performance - biological consequences of using low-drift nozzles. Aspects of Applied Biology 66:79-86.

Media Exposure:

Several media interviews relating to this project were provided for print and radio media:

1. Glenda-Lee Allan of Golden West Broadcasting on strategies to reduce drift incidents (March, 2000).
2. Rosalie Tennison, CAAR Communicator, on Venturi nozzles, one of the top 10 technologies for 2001, Oct. 5, 2000.

3. Ralph Pearce. Sprayer nozzles offer more choice, more options Top Crop Manager, Jan. 25, 2001
4. Jason Griffiths, Venture Communications, on spray drift reduction with air-induced nozzles (Groundswell) May 4, 2001
5. Rob Webber, Seeding Today. Nozzle Pressure - How do you know you have it right? Seeding Today, June, 2001
6. Mike Rayne, Western Producer, features spray technology in story covering Scott field day, July, 2001
7. John Dietz. Consider Flexibility When Choosing A Sprayer, Top Crop Manager, September 28, 2001

Indications for Further Development

These results indicate that the suitability of low-drift sprays depends on several factors, including plant target type (grass or broadleaf) and mode of action.

We have been working with a local nozzle manufacturer to develop a new low-drift nozzle that addresses some of the pattern uniformity concerns with the very coarse sprays tested in this study.

Although our knowledge base for herbicide response to low-drift sprays is now improved, knowledge in insecticides lags behind.

Information of Benefit to Producers, Processors, or Government

- Coarse sprays can be successfully implemented for a wide variety of modes of action on broadleaf weeds under the conditions (water volume and spray pressures) implemented in this study.
- Although efficacy reductions due to spray quality were rare and small in magnitude, caution is advised for very coarse sprays on grassy weeds. Pressure adjustments for very such sprays without air-induction may be appropriate.
- Increased attention may need to be paid to spray patterns, particularly for very coarse sprays. It is possible that the old approach of volumetric uniformity may be misleading, and that the change in spray quality along the swath width may need to be considered in more detail.
- Government regulators should encourage pesticide manufacturers to indicate the suitability of their products' use with coarse sprays on product labels. This would further encourage the environmentally friendly use of crop protection agents.